

Observations of Chlorine and Ozone Evolution in the Lower Stratosphere during the 2005-2006 Arctic Winter from EOS MLS and ACE-FTS

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Although the 2005-2006 Arctic winter began with temperatures dropping more rapidly than usual in December 2005, a major stratospheric sudden warming (SSW) beginning in January 2006 resulted in an abrupt increase in lower stratospheric temperatures. The conditions for a SSW to be "major" were fulfilled on 21~January, and after late January no temperatures below polar stratospheric cloud (PSC) formation thresholds were seen for the rest of the winter. (****Geir, I expect there will be backup for the above assertions in other material submitted? If not, I can provide Figures****). Figure 1 shows maps of nitrous oxide (N₂O, a long-lived tracer) and ozone (O₃) observed by the Earth Observing System (EOS) Microwave Limb Sounder (MLS) instrument [Waters et al, 2006] on NASA's Aura satellite on selected days during this winter at 520 K (~20 km); two scaled potential vorticity (SPV) contours are overlaid in white, indicating the vortex edge region. During January 2006, the vortex became progressively more distorted and shifted off the pole. By 25 January, the lower stratospheric vortex had split, with the largest fragment centered near 50N latitude; by 1 February, the smaller fragments had dissipated, leaving one large fragment, still shifted well off the pole. The vortex never recovered substantially, remaining small, weak, and permeable through the rest of the winter. Until mid-January, N₂O decreased throughout the vortex, and minimum values in the main fragment remained near constant after that; this is consistent with descent dominating the transport until the vortex began to break up during the SSW. In contrast, O₃ inside the vortex appears to decrease throughout the period shown, whereas it would be expected to increase at this level if either descent (since O₃ increases with altitude in the lower stratosphere) or mixing (since highest ozone is along vortex edge) were the dominant process affecting ozone abundances.

The Atmospheric Chemistry Experiment (ACE)-Fourier Transform Spectrometer (FTS) measures the two main chlorine reservoir species, HCl and ClONO₂, by solar occultation [Bernath et al, 2005], providing up to 15 profiles per day in the Arctic winter polar regions. MLS also measures HCl, and ClO, the primary reactive form of chlorine. Figure 2 shows equivalent latitude (EqL, the latitude that would enclose the same area as a given PV contour)-time plots of chlorine species from ACE-FTS and MLS at 520 K; overlaid contours are SPV, with three contours in the vortex edge region shown as solid lines. Because the vortex was distorted and shifted off the pole, ACE-FTS provided good coverage of conditions both inside and outside the vortex after the beginning of January. As can be seen in the top two panels, MLS and ACE-FTS measurements of HCl agree very well. During the cold period before the SSW, the vortex was already highly distorted and shifted off the pole into sunlit regions; as a result, chlorine was activated earlier than in recent cold winters, with substantial enhancement of ClO, along with decreases in HCl, seen by 20 December. By early January, when ACE-FTS had good coverage of vortex conditions, ClONO₂ was also strongly depressed. After temperatures rose above PSC thresholds in

late January, chlorine was rapidly deactivated, with ClO returning to near zero and HCl and ClONO₂ recovering substantially by early February. The few weeks of strong activation, however, allow for the possibility of chemical O₃ loss.

Figure 3 shows EqL-time plots of longed lived tracers (N₂O from MLS and CH₄ from ACE-FTS) and O₃ (from MLS and ACE-FTS) at 520 K; format is the same as in Figure 2. ACE-FTS N₂O (not shown) agrees very well with that from MLS and, as seen in the maps in Figure 1, the evolution of both N₂O and CH₄ suggests that descent was dominating the transport processes until ~20 January. O₃, however, appears to be decreasing in the vortex during the same period, and for a short time thereafter. These changes in the tracers and O₃ are small, however, and interpretation is complicated by large changes in vortex structure, size, and strength during the period.

Figure 4 shows vortex-averaged (within the most poleward of the solid SPV contours overlaid on Figures 2 and 3) MLS N₂O and O₃ between 445 and 600 K (the vortex was not well-defined below 445 K), for 20 December 2005 (red) and 1 February 2006 (black). The decrease in O₃ between ~490 and 580 K, accompanied by a decrease in N₂O (which confirms that transport processes would tend to increase O₃), indicates chemical O₃ loss. Since N₂O decreases with altitude, whereas O₃ increases, the decrease in N₂O over this time period suggests that chemical loss is partially masked by replenishment of ozone via descent. Using N₂O to estimate the descent rate, and applying this to the initial O₃ profile [see, e.g., Manney et al, 2006], we obtain a rough estimate of 0.5--0.7 ppmv maximum vortex-averaged chemical ozone loss at 540 to 570 K. Because mixing would also increase O₃, whereas it would obscure the descent signal in N₂O, this is likely an underestimate of the actual chemical loss. Calculations using both MLS and ACE-FTS data for initial dates in early January yield similar results, and suggest that about 80% of this loss took place between 5 January and 1 February.

In summary, although the major stratospheric sudden warming in mid-January 2006 curtailed any further PSC activity for the rest of the winter, early PSC activity, coupled with a distorted vortex that received considerable sunlight, led to significant O₃ loss during January 2006.

MLS and ACE-FTS observations of the 2005-2006 winter are being used in detailed studies of transport processes throughout the stratosphere during the major warming (Manney et al, in preparation) and of chlorine partitioning throughout the winter (Santee et al, in preparation).

References:

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